ANSWERS: **Relate bp to bonding**

1. FORCES
- hydrogen bonding
- permanent dipoles
- instantaneous dipoles.

The attractive forces due to the hydrogen bonding and permanent dipoles are similar between the molecules in both liquids, as they both have one OH group, which causes the molecule to be polar and take part in hydrogen bonding.

The two molecules have the same mass, and so the same number of electrons involved in the weak instantaneous dipoles.

However, the pentan-1-ol molecule has no side chains and so the main chains can get closer to each other (less steric hindrance, greater surface area), thus the instantaneous dipoles are stronger / greater in pentan-1-ol, and therefore the boiling point is higher.

2. (a) NH_3 = Hydrogen bonds, instantaneous dipoles
F_2 = Instantaneous dipoles
HCl = Permanent dipoles, instantaneous dipoles

(b) NH_3 and HCl both have temporary and permanent dipoles, as they are polar molecules. However, NH_3 has H-bonding, which means the boiling point is higher due to these stronger forces of attraction. HCl has a permanent dipole, but not H-bonding.

F_2 has the lowest boiling point, due to having only temporary dipoles.

3. Between A and B, molecules of ammonia are gaining kinetic energy, and hence the temperature increases.
Between B and C, molecules of ammonia change from liquid to gas. Energy supplied is used to overcome the intermolecular forces rather than increase the kinetic energy of the particles; thus the temperature does not increase until all the NH_3 is in the gas phase.
Between C and D, the molecules of ammonia gas are again gaining kinetic energy, and so the temperature increases.

4. (a) At 100°C, energy is used to change liquid water to water vapour.
At its boiling point, the heat energy is used to break the intermolecular forces /hydrogen bonds between the H_2O molecules.
(b) N_2H_4 is a polar molecule. (Due the presence of the highly polar N-H bonds), there is hydrogen bonding between N_2H_4 molecules.

CH_3F is also a polar molecule. (Due to the presence of the C-F bond), there are permanent dipole attractions between the CH_3F molecules.

The attractive forces due to permanent dipoles in CH_3F must be weaker than the attractive forces due to hydrogen bonding in N_2H_4, because CH_3F boils at a lower temperature and they are similar masses so temporary dipole attractions are similar.

$C_{10}H_{22}$ is a non-polar molecule. The only attractive forces between the $C_{10}H_{22}$ molecules are due to temporary dipoles. However, since $C_{10}H_{22}$ is a significantly larger molecule than N_2H_4, and CH_3F, it is more polarisable / has more electrons / greater molar mass, so its temporary dipole attractions are even stronger than the hydrogen bonds in N_2H_4. As a result, $C_{10}H_{22}$ requires the most heat energy to break its intermolecular forces and therefore has the highest boiling point.

5. Water has a hydrogen atom bonded to an atom with high electronegativity (oxygen) so hydrogen bonding occurs between molecules. The other two molecules do not have hydrogen bonding between molecules. Hydrogen bonding is the strongest of the intermolecular forces; hence it has the highest boiling point.
The instantaneous dipoles present in O_2 and H_2S are similar as the size of the electron clouds is similar. O_2 is a non-polar molecule so it has this instantaneous dipole only. As well as having these instantaneous dipoles H_2S is a polar molecule and has permanent dipole forces between molecules. The effect of these forces of attraction between molecules gives H_2S a higher boiling point than O_2.

6. The instantaneous-induced dipoles (temporary dipoles / dispersion forces / London forces) in each substance are the same as the molar mass and hence the size of the electron cloud is the same.
$CH_3CH_2CH_2Cl$ is a polar molecule so also has permanent dipole force between the molecules.
$HOCH_2CH_2Cl$ is a polar molecule, so also has permanent dipole forces between the molecules.
$HOCH_2CH_2Cl$ has an H atom bonded to an atom of high electronegativity (oxygen), so can form hydrogen bonds (H bond) between the molecules. These are strongest of the intermolecular forces.
So the forces of attraction between $HOCH_2CH_2Cl$ molecules are stronger thus this substance has a higher boiling point.

7. <u>H_2O</u>

- has hydrogen bonding because it has H joined to atom of high electronegativity, causing attraction of H to O on another molecule
- strongest of the intermolecular forces
- more energy needed to break these bonds than other intermolecular forces, therefore higher boiling point.

<u>H_2S to H_2Te</u>

- going down a group molecules have greater molar mass/ more electrons
- stronger temporary dipoles / instantaneous dipoles / London's forces
- more energy required to break bonds, therefore higher boiling point.

As the electronegativities of S > Se > Te decrease down the group, the permanent dipole-dipole interactions will decrease, so boiling points would be expected to decrease. However, as the mass increases, the temporary dipole interactions play a greater role and thus the boiling points increase.

8. (a) The instantaneous-induced dipoles (temporary dipoles / dispersion forces / London forces) in each substance are the same as the molar mass and hence the size of the electron cloud is the same.
$CH_3CH_2CH_3$ is a non-polar molecule so has temporary dipole intermolecular forces only .
CH_3CH_2OH is the same size, so same temporary dipole forces.
CH_3CH_2OH is a polar molecule so also has permanent dipole forces between molecules – these are stronger than the temporary dipoles.
And CH_3CH_2OH also has an H atom bonded to an atom of high electronegativity , so can also form hydrogen bonds (H bond) between the molecules – these are strongest intermolecular force.
So the forces of attraction between CH_3CH_2OH molecules are stronger thus this substance has a higher boiling point.

b) Both molecules are polar, so same permanent dipole forces.
Able to form same hydrogen bonds to other molecules (because the –O–H group is attracted to the O–H of adjacent molecules) so H bonding force the same.
The difference in the boiling points is related to the shape of the molecule – one molecule having a straight chain, the other, a branched chain.
The straight chain butan-1-ol molecules can pack together more closely / less stearic hindrance / more surface area for formation of temporary dipoles than the 2-methylpropan-2-ol molecules,
so even though the molecules have the same molar mass (and so normally same temporary dipole forces) there will be stronger instantaneous / tempoary dipole attraction in the straight chain molecule, thus increasing the boiling point.

9. CH_3Cl has a greater number of electrons / greater molar mass / greater size, so will have stronger **temporary dipole** forces than CH_3NH_2
-*imply both have temporary dipoles.*
Both molecules are polar, and so will have attractions due to **permanent dipoles**.
CH_3NH_2 is able to form **hydrogen bonds (H)** between molecules and this is the strongest intermolecular force.
Similar $\Delta_{vap}H°$ but H-bonding in CH_3NH_2 compensates for greater temporary dipoles in CH_3Cl to give similar overall / net forces of attraction between the molecules so similar $\Delta_{vap}H$.

10. (i) A has hydrogen bonding AND permanent dipole (PD) / temporary dipole (TD) : attractions
B has PD / TD : attractions
Hydrogen bonding is a stronger attraction

(ii) C has PD / TD attractions : stronger
D has TD attractions
(attractions = force = bond)

11. HF has hydrogen bonding,
– the strongest intermolecular force,
– so has the highest BP

– F_2 and HCl have (similar) temporary dipole (or similar) forces (as they have same number of electrons)
– However HCl also has, permanent dipole forces (or similar)
–- giving it a higher BP than F_2.

12. Ethanal, propanal and butanal are all aldehydes. They all have weak intermolecular or permanent dipole forces attracting molecules together. $\Delta_{vap}H^\circ$ increases from ethanal to butanal due to increasing M / electron numbers. The greater the M / electron numbers the greater the strength of intermolecular or temporary dipole forces.
Ethanoic acid has an H atom bonded to an O atom so can form H-bonding between molecules.
H bonding is a stronger intermolecular attraction compared to temporary and permanent dipole forces between the aldehydes.

13. Propanoic acid has lower melting point than butanoic acid because same intermolecular forces (both acids) but Propanoic acid has a smaller mass / less electrons than butanoic acid hence temporary dipoles are weaker.
Ethyl ethanoate has a lower melting point because it cannot form hydrogen bonds between molecules, so intermolecular forces are weaker than for the two acids .

14. (a) It is the enthalpy change when one mole of a solid is melted to its liquid state under standard conditions.
(b) Heptane
Heptane is a small non-polar molecule so the only intermolecular forces are weak. This means heptane will have low values for melting point, boiling point and heats of fusion as all are measures of the strength of intermolecular forces.
Sodium Chloride
Sodium chloride is an ionic solid with strong ionic bonds between all ions in the 3-D network. Water has hydrogen bonds between its molecules and this type of intermolecular attraction is stronger than the instantaneous dipole-dipole attractions that exist between the non-polar heptane or nitrogen molecules. This type of attraction is greater for heptane than nitrogen because of its larger electron cloud/molar mass.
Specific comparisons or justifications that can be made include:
• Boiling point of heptane should be higher than its melting point.
• Melting point for heptane is wrong as it is a liquid at room temperature.
• The high heat of fusion for heptane is inconsistent with its low boiling point.
• The boiling point of heptane should be higher than that for nitrogen.
• The heat of fusion for heptane should be lower than the value for either NaCl or H_2O.
• The melting point for heptane should be lower than that for water.
• Heptane has a boiling point much lower than water so also should have a heat of fusion that is much lower – contradictory.